Studies of Plasma Irregularities and Convection in the Polar Ionosphere using HILAT, SABRE and EISCAT

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A statistical study of the F-region main ionospheric trough has been undertaken with EISCAT common programme data to assess the possibility that the trough region is a perferntial region for the generation of E-region irregularities. Three years of CP-3 data from EISCAT formed the basis of this study. Backscatter observed by the coherent radar, SABRE, was also utilised to study the occurrence of irregularities in the E-region. On 26 out of the 36 days when the trough was observed by EISCAT, SABRE observed coherent backscatter. Although this percentage seems high, there was no consistent relationship between the latitude of the trough minimum and the latitude of peak backscatter intensity.

A case study involving a four day run of EISCAT in September 1986 indicates that the trough latitude can be affected by changes in the Interplanetary Magnetic Field north-south component. On two days rapid decreases in the latitude of the trough were related to a southward turning of the IMF and the onset of backscatter. The high perecntage of occurrence of trough and backscatter is believed to be caused by enhanced convection.

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Studies of Plasma Irregularities and Convection in the Polar Ionosphere using HILAT, SABRE and EISCAT.

1. Introduction.

The main aim of this study is to provide new insight into the generation, propagation and decay of scintillation producing plasma irregularities in the high latitude ionosphere. Kilometer-scale plasma irregularities in the F-region can cause scintillation phenomena on trans-ionospheric UHF communication links, thus seriously degrading the system performance. It is, therefore, important to understand more fully the generation, motion and decay of these irregularities. The SABRE radar, which measures coherent backscatter from plasma irregularities in the E-region is the principle instrument employed in this study. Other data from EISCAT and the HILAT spacecraft are also utilized.

To achieve the aim of this study, three topics were identified for co-ordinated study:

1. The morphology and dynamics of the cusp and its role as a source of structured plasma for the high latitude ionosphere.
2. The morphology and dynamics of the mid-latitude ionization trough, particularly its poleward edge, as a source of scintillation producing irregularities.
3. The high-latitude plasma convection pattern as a function of latitude and parameters of the interplanetary environment, and its role in the re-distribution of structured plasma within the polar ionosphere.

In the initial phase of this study (*Jones et al., 1988*), the third of these topics was considered, together with an investigation of the coherent radar backscatter amplitude. This study indicated that the B_z component of the IMF determined whether flows are observed by SABRE (i.e. the latitudinal extent of the large scale convection pattern), while B_y exerted a strong control of the convection flow in the Harang discontinuity region. Furthermore, a strong empirical relationship between the radar backscatter intensity and solar wind parameters, such as ε, was established. A preliminary study also demonstrated the existence of periodic perturbations in the high latitude ionosphere with periodicities of ~27 days and ~13.5 days. The latter probably arises from a temporally stable two sector heliospheric structure, resulting in the enhancement of kinetic and magnetic parameters of the interplanetary medium twice per solar rotation.

In the second phase of the study a statistical investigation of the mid-latitude F-region trough is undertaken, to determine if E-region backscatter is more likely to occur when the trough is within the SABRE field of view A study of the

A-1

relationship between the latitude of the trough minimum and the latitude of radar backscatter was also undertaken. A more detailed case study of the F-region trough dynamics is also reported.

2. Instrumentation.

The Sweden And Britain Radar-Auroral Experiment, SABRE, (*Nielsen et al., 1983*) comprises two multi-beam coherent radars. Each radar measures two parameters, the backscatter intensity and the line of sight Doppler velocity of plasma irregularities that propagate in the auroral E-region with a phase velocity related to the electron drift velocity. The SABRE radars are located at Wick, Scotland and Uppsala in Sweden and the beam geometry is illustrated in Figure 1.

The European Incoherent SCATter facility (EISCAT) comprises a tristatic UHF incoherent radar, with a transmitter/receiver at Tromso, Norway, and receivers at Kiruna, Sweden and Sodankyla, Finland, and a monostatic VHF incoherent radar at Tromso (*Baron, 1984*). Data from the UHF system only will be considered here. EISCAT operates in three common modes on a routine basis and data from the Common Programme (CP-3) mode forms the basis of this study.

CP-3 is designed to provide a latitudinal scan through the ionosphere approximately along a magnetic meridian. The scan time is 26 minutes, with each scan starting on the hour and at 30 minutes past the hour. The scan consists of a number, typically 17, of antenna pointing positions, 16 of which follow approximately the magnetic meridian which passes through Tromso and Kiruna. At each position, line of sight data are taken at Tromso with range resolution dependent upon the pulse length and the remote site beams intersect the Tromso beam at a common height, typically 275 kms, for each scan position. This allows the tri-static ion velocity to be calculated in the F-region. The line of sight data from Tromso provide information on electron density, electron temperature and ion temperature (see *Beynon and Williams, 1978* for a review of the incoherent scatter technique). At 275 kms altitude, the scan covers a geographic range from 64 ^{o} N to 75 ^{o} N (approximately 61 - 72 ^{o} magnetic latitude).

3. Survey of the mid-latitude trough.

The mid-latitude trough is a region of abnormally low electron concentration in the F-region which occurs just equatorward of the auroral oval (see *Moffett and Quegan, 1983* for a review). As such, there are strong gradients in electron concentration, particularly at the poleward edge of the trough, both in the F-

region due to the trough and in the E-region due to particle precipitation, and these gradients may be unstable to the formation of plasma irregularities. The formation of the trough remains a subject of some debate. The association between the trough minimum and strong westward convection flow which can move plasma across the pole from the dayside into the nightside region and then round into the dusk sector has been considered as one mechanism for the formation of the trough in the afternoon LT sector (*Collis and Haggstrom, 1988*). The effect of enhanced chemical processes may also be important as pointed out by *Schunk et al., (1976)*. As the flux tubes are transported into the nightside region ionization production is removed and the electron concentration starts to decrease. The depleted flux tubes, then if they are transported past the dusk terminator into the sunlit region, form the main F-region trough in the post noon local time sector. Certain models suggest that plasma transport processes play a role, but through stagnation of flux tubes in the dusk local time sector due to competing convection and corotation electric fields (*Spiro et al., 1978*) or simply by extending the lifetime of the flux tube in the nightside region (*Knudsen, 1974*). Whatever the mechanism, for trough formation in the post noon and dusk local time sectors, plasma transport plays an important role.

The EISCAT CP-3 experiment provides a data set which can be employed in a morphological study of the main F-region trough, since the scan covers a range of latitudes. In this study, three years of CP-3 data, from 17 January 1984 to 11 November 1986, have been surveyed for features of the trough. This was undertaken by plotting electron concentration, N_e, electron temperature T_e, ion temperature, T_i, and the tri-static ion velocities, v_i, at 275 km altitude and the corrected power profile, PP, measurements at 110 km altitude. The study relied predominantly on N_e and v_i at 275 km and, to a lesser extent, PP at 110 km. We note that often there are elevated ion temperatures associated with the trough caused by enhanced ion velocities which result in frictional heating from the relative motion of the ions and neutrals. Elevated T_e can also occur at the poleward edge of the trough due to electron precipitation and within the trough due to the lower electron concentration. Also, note that for given aspect angles under certain conditions when the ion velocity is high, the plasma can be driven non-thermal resulting in non-Maxwellian incoherent radar spectra (*Winser et al., 1987*). This can result in overestimates of N_e and T_i and underestimates T_e (*Moorcroft and Schlegel, 1988; Lockwood et al., 1988*) This has been neglected for the purposes of this study.

The distribution of the intervals of CP-3 data throughout the year (Figure 2, upper panel) is somewhat uneven, with fewest number of days of CP-3 data in May (2) and most in October (9). However, there are trends in the data which can be identified. Of the 54 days of CP-3 data, there were 36 observations of the

trough (Figure 2, upper panel). The shaded regions in the upper panel of Figure 2 indicate the occurrence of the trough each month. Clearly the trough is more likely to be observed with the EISCAT CP-3 mode in the equinoctal months and the northern winter months, but does not occur at all near the summer solstice, May - July inclusive. This is in agreement with most other studies (see for example *Collis and Haggstrom, 1988*). The local time coverage of the trough as the radar moves underneath it or as the trough moves across the EISCAT CP-3 field of view is typically in the post noon to pre midnight local time sector; the exact time of the observation of the trough does depend to some extent on the general level of magnetic activity (*Rodger and Pinnock, 1982*).

A comparison of times when the trough was detected by EISCAT with times when the Wick radar received coherent backscatter indicates a high percentage of coincidence. In 26 cases out of the 36 intervals when the trough was observed, so too was coherent backscatter in part of the trough local time sector (Figure 2, lower panel). On another 5 occasions backscatter occurred within 1 hour of local time of the trough (data not shown in Figure 2). During the 18 intervals when no trough was observed, there were 12 examples when backscatter occurred during the 12 - 24 UT interval, the intervals when the trough is observed by CP-3. Such a simple comparison is somewhat limited. For example, one has to bear in mind the difference in the longitudes of the two data sets, although a study by *Lester et al. (1989)* shows that the latitude of trough minimum remains reasonably stable in local time (see section 4). Furthermore, the percentage occurrence of trough and backscatter, 72%, is not appear significantly different from the percentage of times when backscatter occurred for part of the 12 - 24 UT interval when CP-3 was running. This is a rather more relaxed criterion than the one used for trough and backscatter occurrence, which required an overlap in local time.

A further study was undertaken which compared the latitude of the trough minimum, a characteristic of the trough which is easily defined and relatively easily located with the CP-3 data, with three parameters of the coherent backscatter, the latitudes of the poleward and equatorward borders and the latitude of the peak backscatter intensity. If E-region backscatter were preferentially generated at some region of the trough then we would expect a consistent picture to emerge from this study. However, not one of the backscatter parameters was found consistently to relate to the trough minimum latitude. Two examples of the comparisons are given in Figure 3 to illustrate the inconsistency. On 24 September 1986, Wick backscatter began at ~ 1800 UT (~ 1900 LT). At this local time the trough as measured by EISCAT was between ~ 66 ^{o} N magnetic latitude and ~ 63 ^{o} N magnetic latitude (Figure 3, upper panel, open circles). The peak backscatter intensity started near 64 ^{o} N and moved

equatorward over the next hour by ~ 1 ^{o}, and remained very close to the trough minimum. The backscatter exhibited a poleward border which also had an equatorward motion throughout the interval. The equatorward border remained at ~ 62.5 ^{o} N magnetic latitude, very close to the lowest latitude of the field of view. Compare these observations with those of 26 September 1986 (Figure 3, lower panel). The backscatter onset on this day was ~ 1600 UT (~ 1700 LT), when the trough was between 67 ^{o} N and 66.5 ^{o} N magnetic latitude. The peak backscatter was some 3 ^{o} equatorward of the trough position, apart from the last 15 minutes or so of the interval, when the trough minimum had moved equatorward (see also section 4). Neither the poleward or equatorward borders moved in the same manner as the trough. The inconsistency demonstrated by the above examples leads us to the conclusion that we cannot determine if there is preferential generation of irregularities in the E-region associated with the F-region trough from this statistical study alone.

4. Case Study: 22 - 26 September, 1986.

This interval forms part of the SUNDIAL campaign, during which an extended 4 day run of all the incoherent scatter radars was planned. EISCAT operated CP-3 during the bulk of this interval. The trough was observed on all 4 days, and the latitude of the minimum of the trough (Figure 4) moved across the radar field of view at different times (*Lester et al., 1989*). Two days have already been discussed and the trough motion for part of the time noted. There are several interesting features about the day-to day variability of the trough minimum during this interval. On the 25 September, there was a rapid decreases in the latitude of the trough minimum, from 69 ^{o} N magnetic latitude to 63 ^{o} N magnetic latitude. Since the time resolution is poor, only 30 minutes, exact timing is difficult, but the decrease started between ~ 1240 UT and ~ 1320 UT. The EISCAT magnetometer cross observed an enhancement of some 300 nT in the North-South component of the magnetic field, implying an enhanced eastward electrojet, between 1310 UT and 1420 UT. Also at 1315 UT SABRE observed the onset of backscatter, which lasted until 1500 UT within the whole field of view (Figure 5). The EISCAT ion velocity perpendicular magnetic field at 275 km (Figure 6) was also enhanced on each scan from that starting at 1300 UT until that starting at 1430 UT. Initially, flows larger than 1 km s^{-1} were observed in a localised latitude region, but eventually over much of the field of view. Observations by IMP-8 indicate that a southward turning of the IMF occurred at ~ 1255 UT and B_z stayed southward, apart from a 10 minute interval, until 1440 UT. The southward turning was clearly responsible for the onset of backscatter at SABRE and the measurements of enhanced convection by EISCAT. This is likely to be the cause of the equatorward motion of the trough on this day.

Further evidence for some IMF control of the dynamics of the trough is present in the EISCAT data from 26 September. Again there was a rapid equatorward motion of the trough minimum, but this time between 1600 and 1630 UT. SABRE again observed the onset of backscatter near the time the motion started, i.e. 1600 UT as mentioned earlier, and EISCAT observed enhanced convection on the scan starting at 1530 UT. Although the IMF data are less clear on this occasion due to a data gap between 1532 and 1602 UT, the IMF was southward in the 15 minutes prior to the data gap and in the hour or so after the data gap. One point that should be noted is that the equatorward motion of the trough due to the IMF change on the 26 September may be the cause of the discrepancy between the trough latitude and backscatter intensity maximum. The trough clearly moved rapidly equatorward after 1600 UT and the coincident observations in Figure 3 were taken at the time when the trough minimum was moving rapidly equatorward. The difference in longitudes of the two radar fields of view then becomes important.

Clearly these observations indicate that SABRE observes backscatter at some local times when EISCAT has observed the trough. However the exact relationship appears to be controlled more by the convection pattern, or IMF, than preferential generation of backscatter occurring at the poleward border of the trough. In the post noon and pre midnight sectors the trough appears to be associated with westward convection velocities. This is apparent from Figure 7, where the average east-west velocity component in the regions within the trough and poleward and equatorward of the trough are plotted for each of the four days during the extended run. In general, the ion velocity has a mean westward component of some 500 m s^{-1}, often approaching 1 km s^{-1}. On the one occasion where the ion velocity within the trough was eastward, the mean ion velocity equatorward of the trough was westward. These observations suggest that the trough in the afternoon local time sector is formed in the region poleward of the so called stagnation region.

As mentioned earlier one of the limitations of the statistical comparison between trough occurrence at EISCAT and backscatter occurrence is the different longitudes of the two observations. This case study can also shed some light on this limitation since both the Millstone Hill and Sondrestrom incoherent scatter radars were operational on 2 and 4 days, respectively, of the interval. Comparison of trough latitude at the three radars demonstrates that the trough minimum occurs at very similar latitudes at the same local time. This is illustrated by a comparison of the trough minimum latitude at EISCAT and Millstone Hill for the two days when Millstone Hill data were available (Figure 8). Although the meridians of the two radar scans were separated by some 90 ^{o} in longitude, the differences in the latitude of the trough minimum is typically less than a few degrees of latitude. The one day where observations of the trough at

EISCAT and Sondrestrom Fjord overlapped in local time is consistent with this result. Unfortunately, it is not possible to study the effect of the changing IMF, which can rapidly change the latitude of the trough minimum, on the constancy of the trough latitude from the EISCAT meridian to the Millstone Hill meridian due to lack of Millstone Hill data on 25 and 26 September. A more extended comparison is needed to confirm this observation. However, this observation does give more confidence in the results of the statistical study, in particular since the longitude difference between EISCAT and SABRE is considerably less than that between EISCAT and Millstone Hill.

5. Conclusions.

The statistical study suggested at least a coincidence between F-region trough occurrence and E-region backscatter occurrence for ~ 70% of the time. However, this is probably not significantly better than the normal occurrence of backscatter when CP-3 observations are made. Furthermore, a study of the latitude of backscatter peak intensity and the poleward and equatorward edges to the backscatter proved inconclusive with regard to a relationship to the trough minimum. The inconsistency of the results was illustrated with two examples. However, a detailed case study of the trough on 4 days suggests that in fact any relationship is due to similar formation mechanisms, rather than preferential generation. The trough formation mechanism within the post noon sector and one of the irregularity generation mechanisms, i.e. the two-stream instability (*Fejer and Kelley, 1980*) are both related to enhanced ion convection. The F-region trough may still be an important location for the generation of irregularities in the F-region ionosphere which would affect HF coherent radars and cause F-region scintillation.

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Figure Captions.

Figure 1. The beam geometries for the two radars at Wick and Uppsala that constitute SABRE.

Figure 2. The occurrence frequency of the F-region trough observed by the EISCAT CP-3 programme for the three year interval 1984 - 1986. The upper panel gives the distribution of CP-3 observations and trough occurrence. The lower panel gives the trough occurrence and the occurrence of those intervals when backscatter was also observed by SABRE.

Figure 3. The variation of the latitude of the trough minimum with local time together with the latitude of the peak backscatter intensity the latitude of the equatorward border of the backscatter (EB) and the poleward border of the backscatter (PB). The upper panel is for 24 September and the lower panel for 26 September.

Figure 4. The latitude of the minimum of the trough observed by EISCAT on the four days of the SUNDIAL 86 campaign. The error bars represent the latitude range over which the electron concentration is within 25% of the minimum value.

Figure 5. The SABRE irregularity drift velocity for the interval 1200 - 1800 UT on 25 September 1986. The data have been averaged over 15 minutes and the longitude range 5.0 to 7.0 degrees east.

Figure 6. The EISCAT ion velocity measured perpendicular to the magnetic field for the same interval as in Figure 5.

Figure 7. The mean ion velocities measured by EISCAT poleward (closed circles), within (open circles) and equatorward (crosses) of the trough for all four days of the SUNDIAL 86 interval.

Figure 8. The latitude of the trough minimum measured by EISCAT (squares) and Millstone Hill (diamonds) plotted against local time on the first two days of the SUNDIAL 86 campaign.

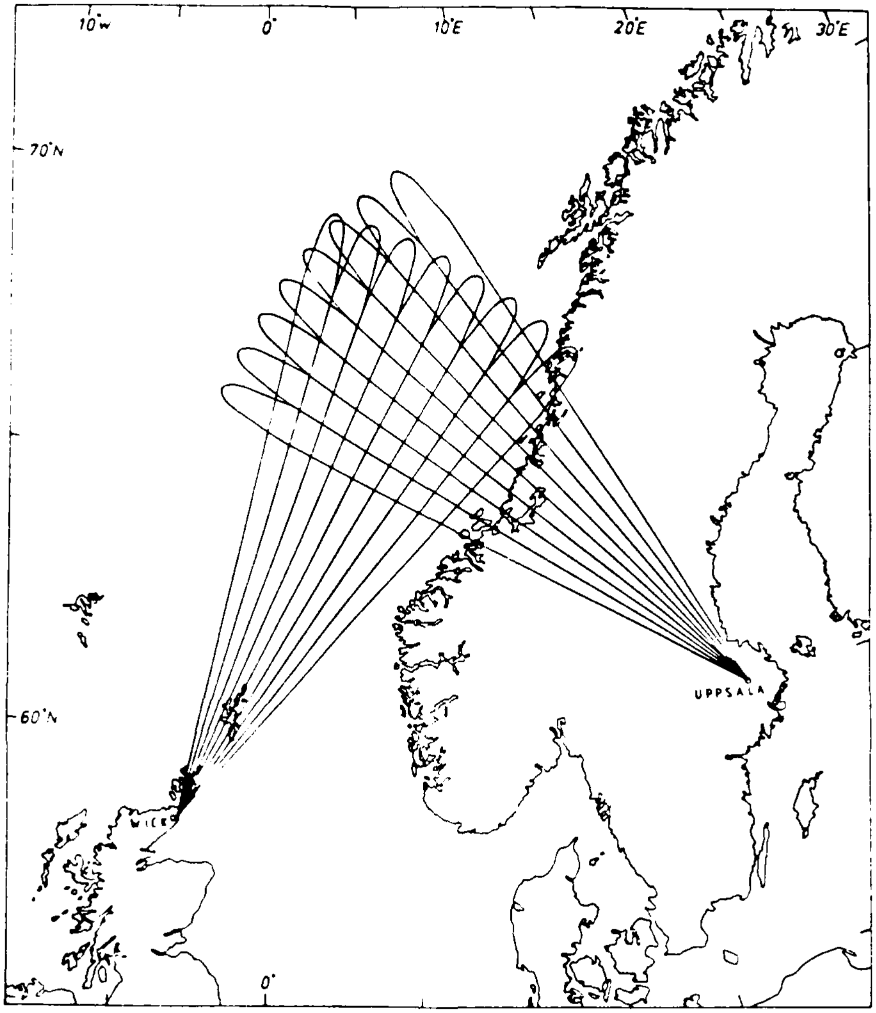
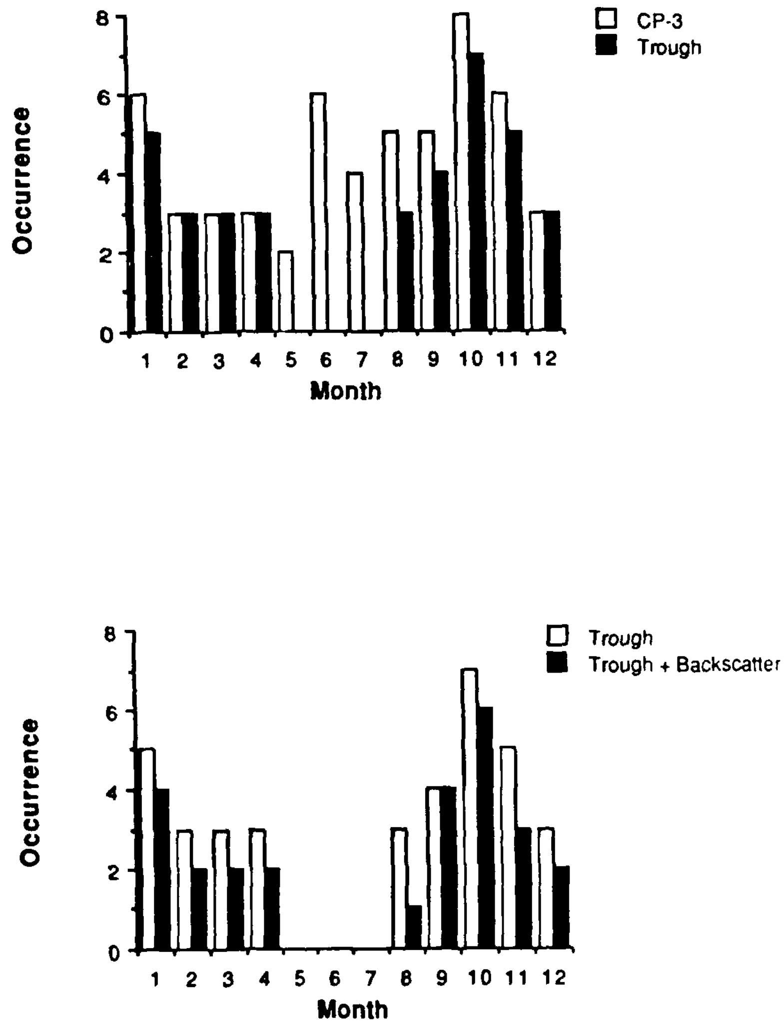


Fig. 1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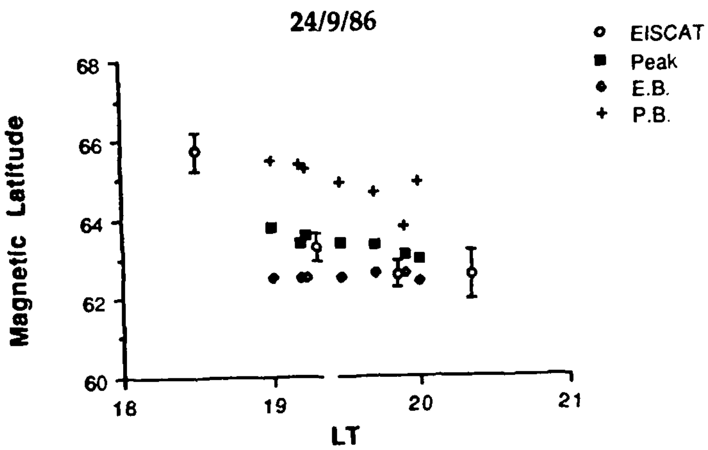
Trough
Occurrence
Month
Trough
Trough + Backscatter
Occurrence
Month

Fig. 2.


24/9/86
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E.B.
P.B.
Magnetic Latitude
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66
64
62
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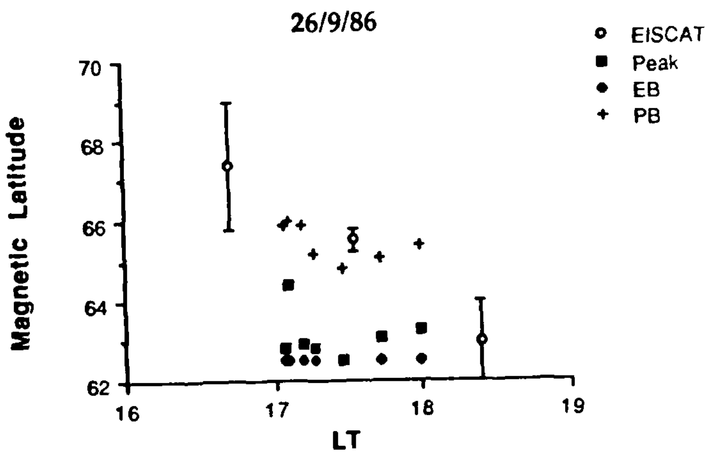
18
19
20
21
LT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16
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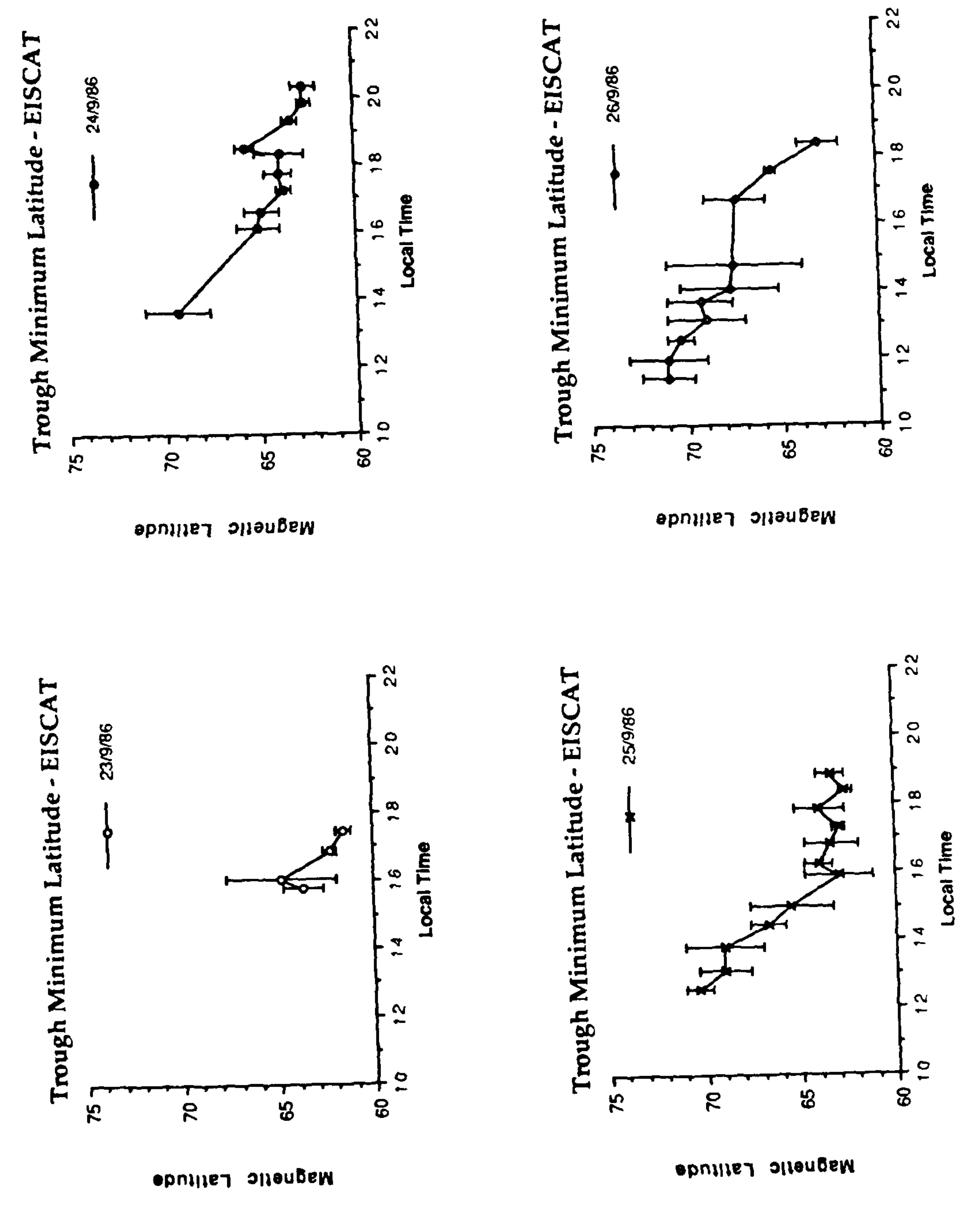
LT

Fig. 3.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24/9/86
Magnetic Latitude
Local Time
Trough Minimum Latitude - EISCAT
26/9/86
Magnetic Latitude
Local Time
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23/9/86
Magnetic Latitude
Local Time
Trough Minimum Latitude - EISCAT
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18
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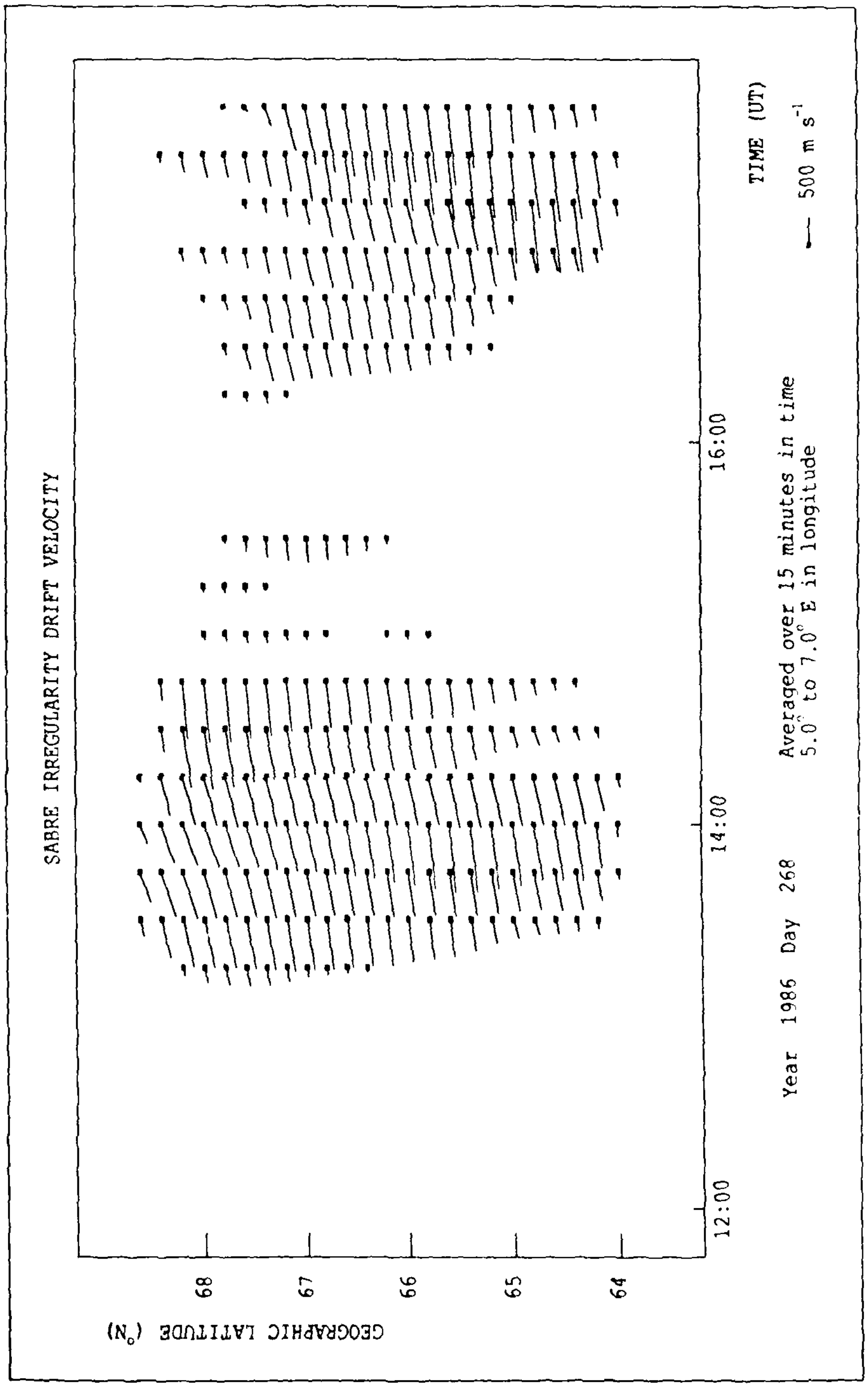
22

Fig. 4.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66
65
64
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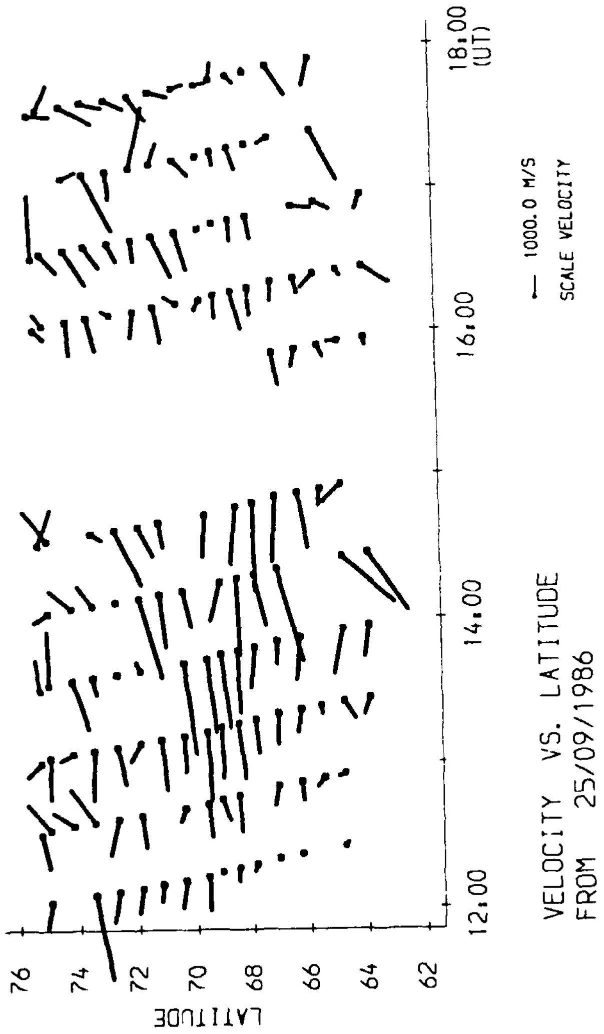
14:00
16:00
TIME (UT)
Year 1986 Day 268
Averaged over 15 minutes in time
5.0° to 7.0°E in longitude
500 m s⁻¹

Fig. 5.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FROM 25/09/1986
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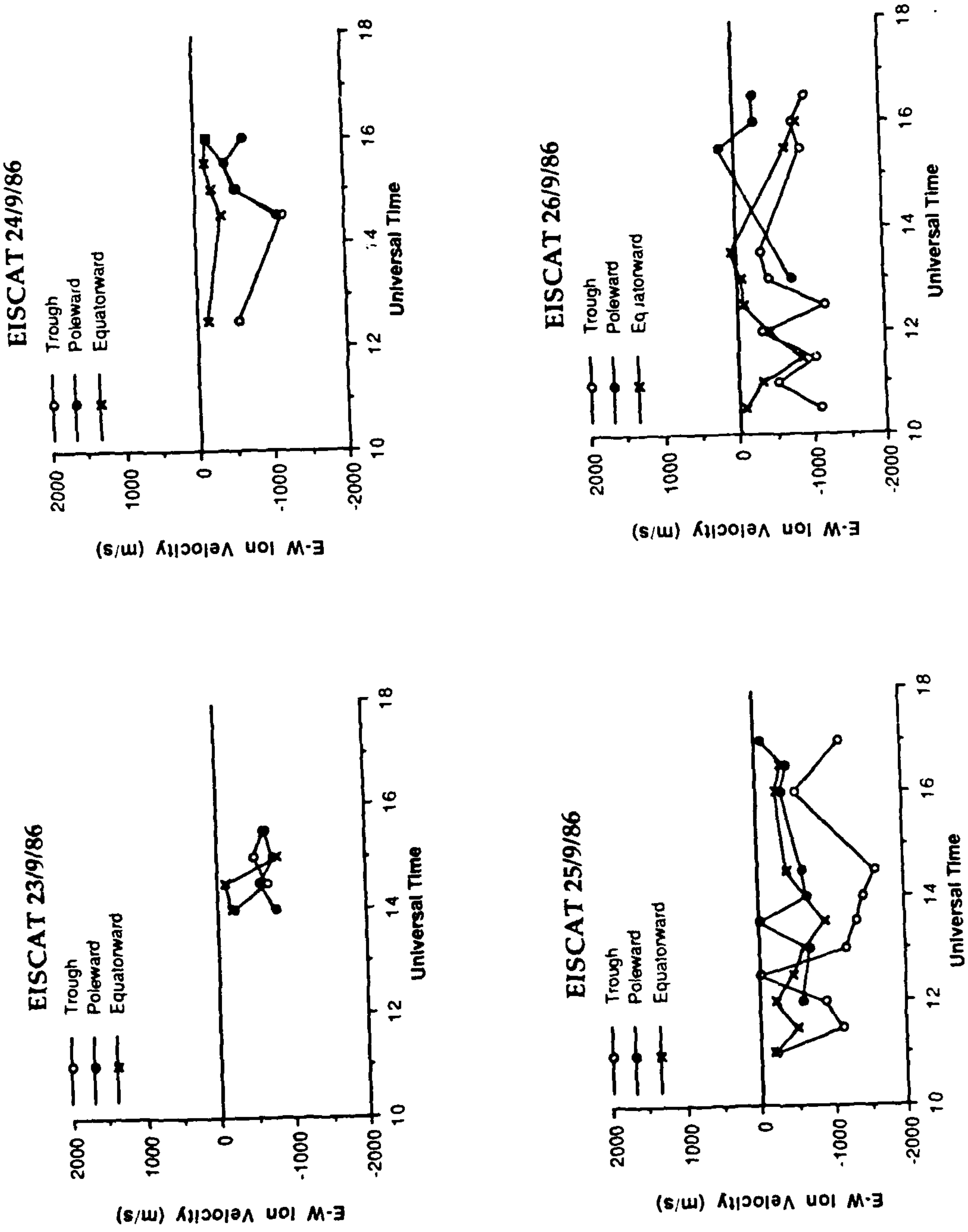
Fig. 6.



EISCAT 23/9/86
EISCAT 24/9/86
EISCAT 25/9/86
EISCAT 26/9/86
Trough
Poleward
Equatorward
E-W Ion Velocity (m/s)
Universal Time
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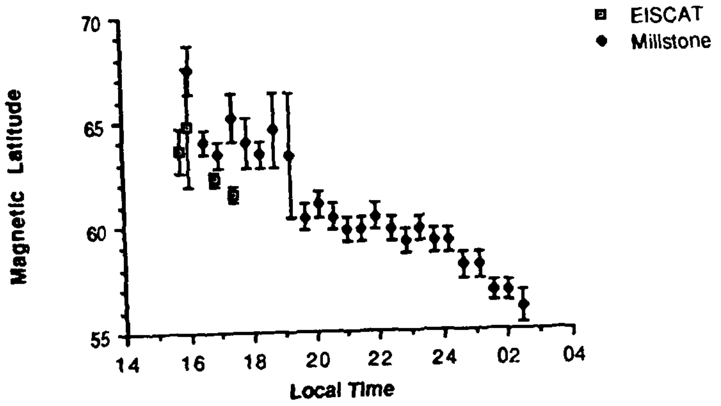
1000
0
-1000
-2000
10
12
14
16
18

Fig. 7.

Trough Minimum Latitude 23-24/9/86



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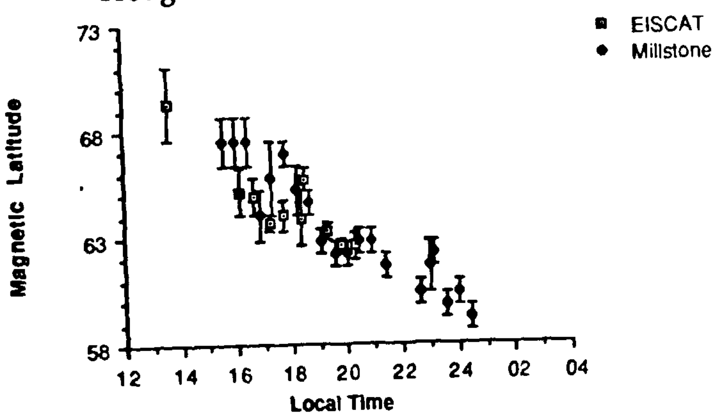

Fig. 8.